XXXI International Workshop on Deep Inelastic Scattering and Related Subjects (DIS2024)
Grenoble, France, from April 8 to April 12, 2024.

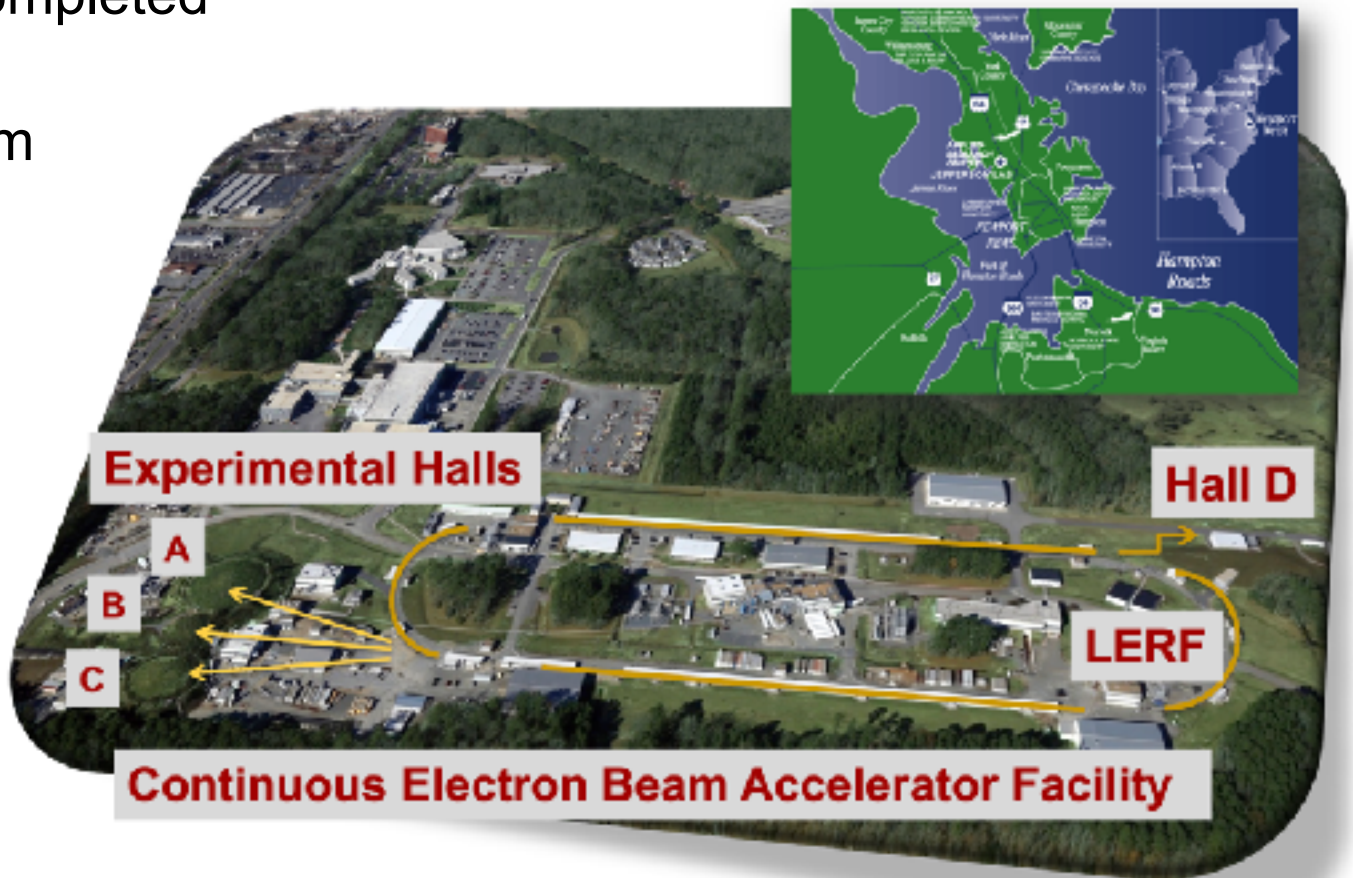
The CLAS12 luminosity upgrade and future physics opportunities

M. Bondì - INFN
For CLAS12 collaboration

Jefferson Lab - Experimental overview (1)

CEBAF upgrade completed in September 2017

- CW electron beam
- E_{max} = 12 GeV
- I_{max} = 90 mA
- Pol_{max} ~90%

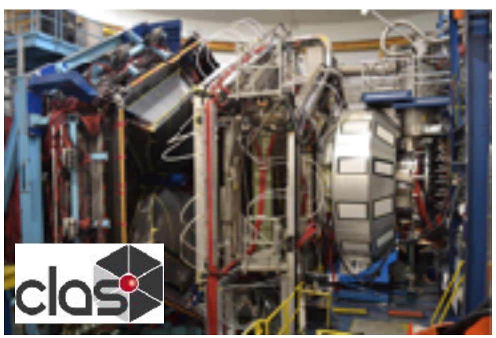


Physics operation

- 4 Halls running simultaneously since January 2018

Jefferson Lab - Experimental overview (2)

HALL C - precision determination of valence quark properties in nucleons and nuclei

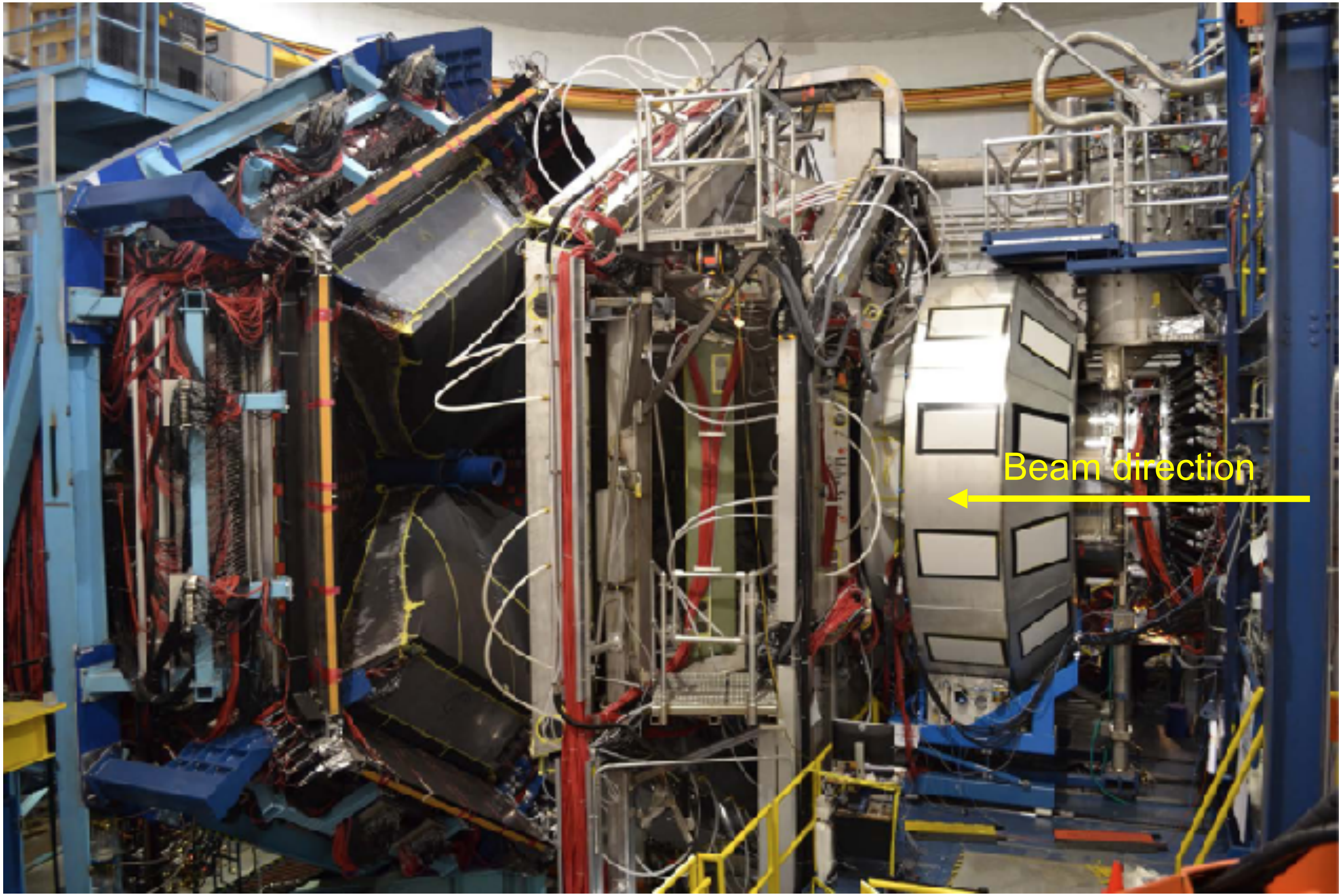


HALL B - understanding the 3D nucleon structure, hadron spectroscopy and nuclear effects

HALL D - exploring origin of confinement by studying exotic mesons

HALL A - form factors and PDFs, hyper nuclear physics, Physics BSM

CLAS12 in JLAB-HALL B



CLAS12 - Detector

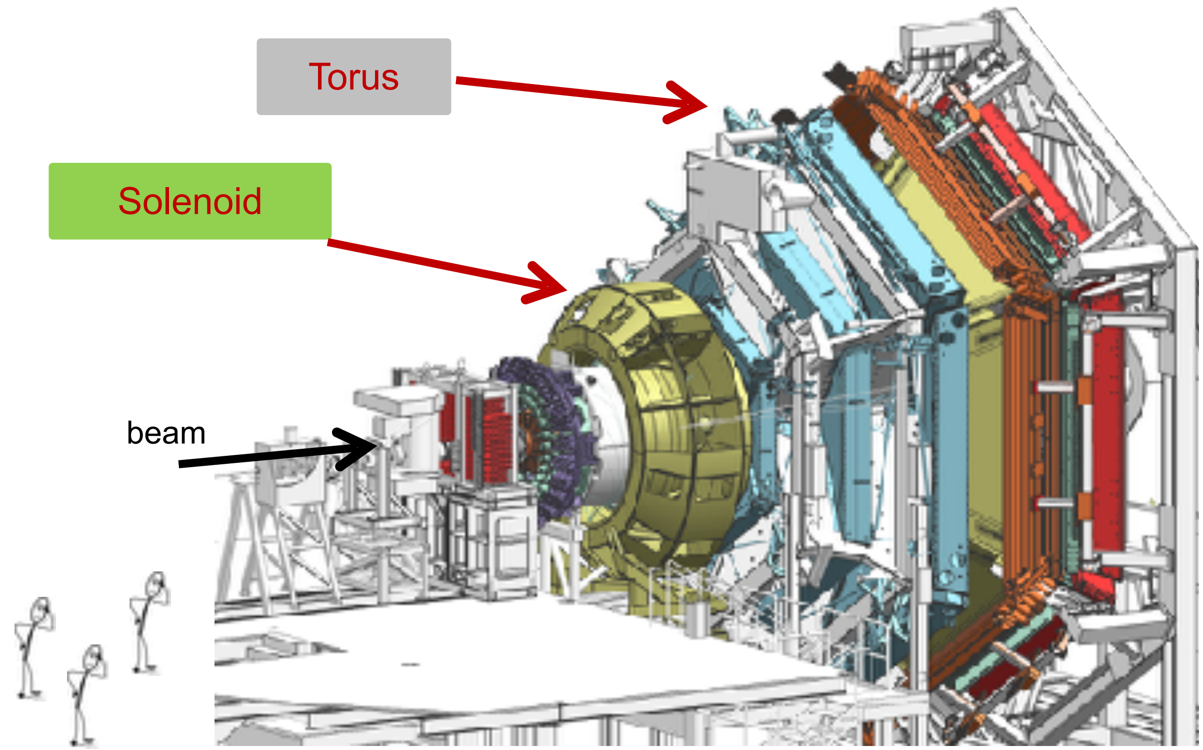
CENTRAL

- Beamline
- Target
- Central Vertex Tracker
- Central Time of Flight
- Central Neutron Detector
- Back-Angle Neutron Detector

	Forward	Central
Angular coverage	$5^o - 35^o$	$35^o - 135^o$
Momentum resolution	$dp/p < 1\%$	$dp/p < 5\%$
θ resolution	1 mrad	5 – 10 mrad
ϕ resolution	1 mrad/sinθ	5 mrad/sinθ

FORWARD

- High Threshold Cherenkov
- Forward Tagger
- Drift Chambers
- Low Threshold Cherenkov
- Ring Imaging Cherenkov
- Forward Time of Flight
- EM Calorimeter



Design Luminosity:

- **10^{35} cm^{-2}s^{-1}**

Physics targets:

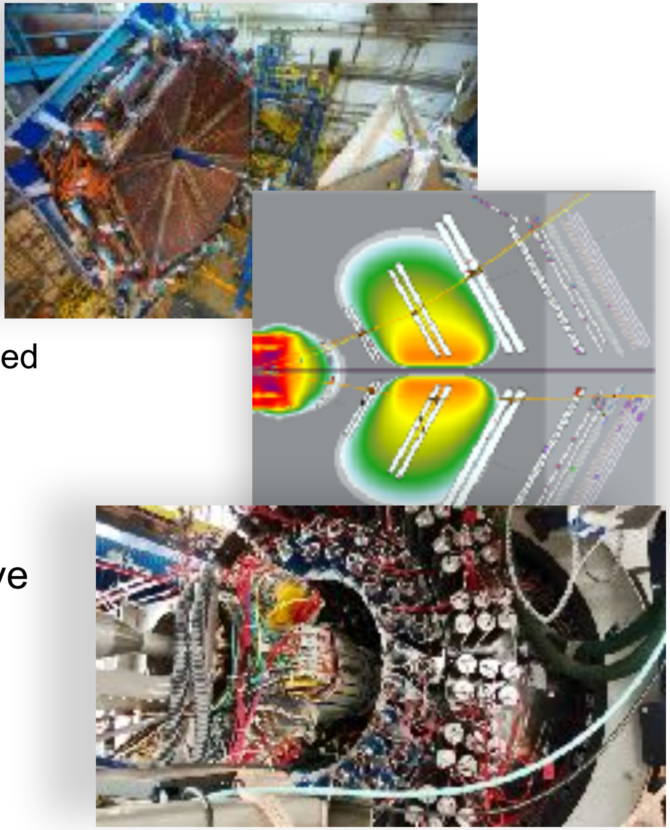
- LH_2, LD_2, LHe, LAr
- D, ^4He
- ^{12}C to ^{208}Pb
- Polarized NH_3, ND_3, ^6LiH, ^7LiD, ^3He-gas

CLAS12 in numbers

Collaboration:

- More than 200 members
- 43 institutions
- 9 countries

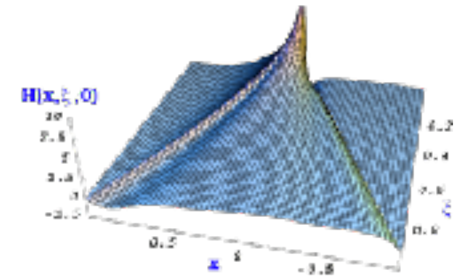
Experimental program:



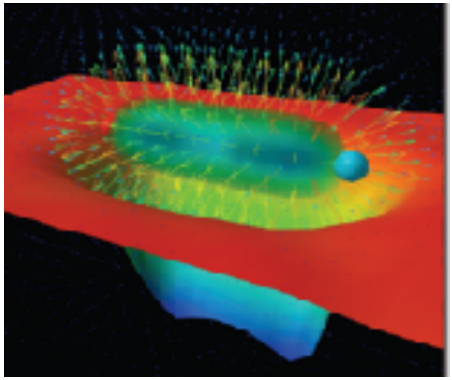
- 47 approved proposals:
  - targets:
    - proton, deuteron and nuclei
    - unpolarized, longitudinally and transversally polarized
    - solid, liquid and gas
  - beam:
    - highly polarized electron beam
    - linearly polarized quasi-real photons
  - final states: inclusive, semi-inclusive and exclusive
  - luminosity up to 10^{35} $cm^{-2}s^{-1}$
- 3188 PAC days
- 12 Run Groups
- 1171 Run Group days
- **10 years of approved data taking**

CLAS12 physics program

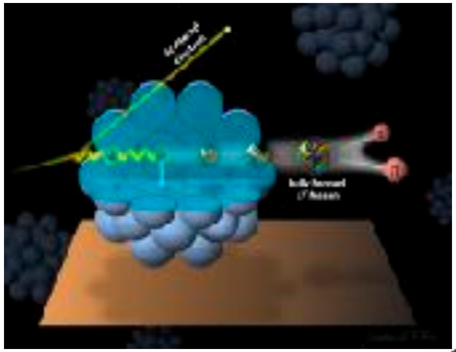
- The multidimensional structure of the nucleon – from form factors and PDFs to GPDs and TMDs



- Quark confinement and the role of the glue in meson and baryon spectroscopy



- The strong interaction in nuclei – evolution of quark hadronization, nuclear transparency of hadrons, short range correlation

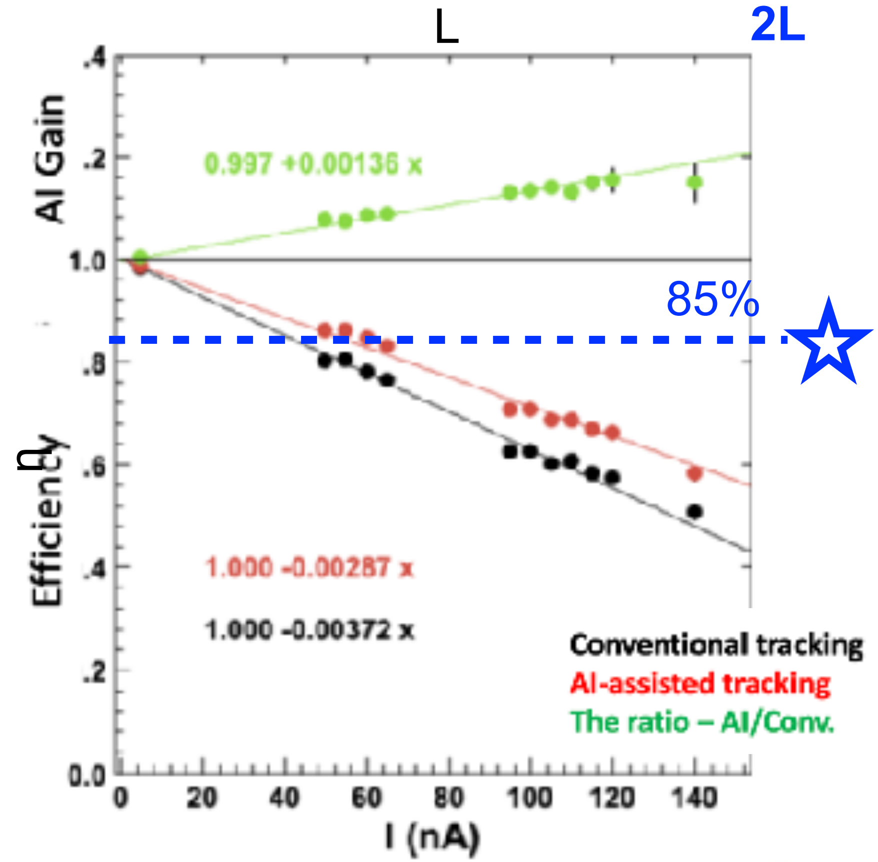


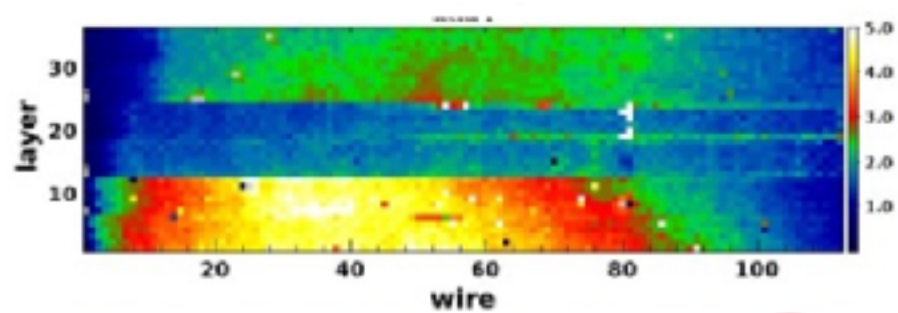
CLAS12 Luminosity upgrade, staged approach

- **Phase1**: achieve luminosity of $2x10^{35}$ $cm^{-2}s^{-1}$ for CLAS12 normal running conditions with charged particle reconstruction efficiency of >85%.
  - To support efficient and fast execution of the current program;
  - Support a growing demands of physics program with a low rate, exclusive reactions (TCS, J/y production,…);
  - Will need to upgrade forward tracking. The beam-line and the rest of the detector systems will perform at x2 higher luminosity;
- **Phase2**: achieve two orders of magnitude higher luminosities: μCLAS12 at > 10^{37} $cm^{-2}s^{-1}$
  - New physics opportunities for CLAS12 – DDVCS and e-J/ψ;
  - Requires a large acceptance forward calorimeter (FTCal-Large), a recoil detector and a forward vertex tracker

CLAS12 Luminosity upgrade - Phase 1 - Motivation

- The limitation for running above the designed luminosity is the FD track reconstruction efficiency defined by the occupancy in R1 of DC
- Significant efficiency recovery has already happened with AI/ML-based software techniques
- Tracking hardware improvements will also be required to keep occupancies and efficiencies acceptable and achieve 2x luminosity

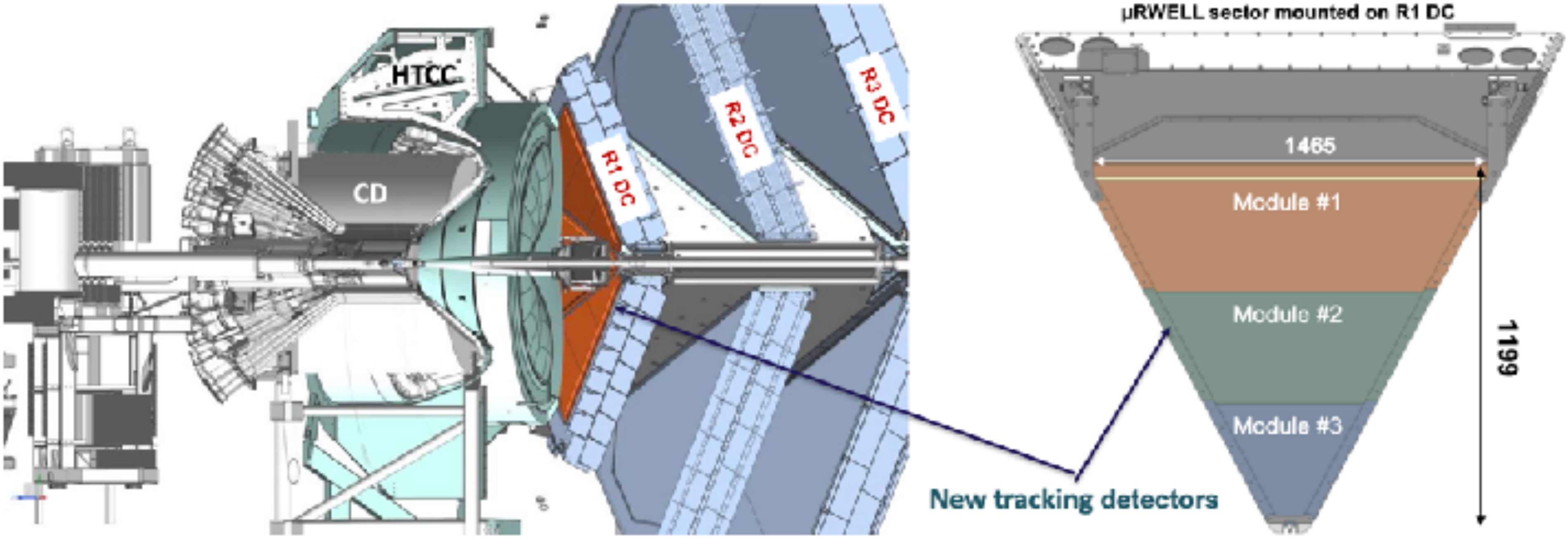




FD tracking efficiency needs an upgrades to get close to η ≥85% at 2L

CLAS12 Luminosity upgrade - Phase 1 - Plans

To mitigate occupancy-related inefficiency of FD tracking, we plan to add faster tracking detectors to the forward drift chambers.



- Each layer will consist of 6 triangular large sectors
- Each sector will consist of three modules (there are no foils large enough to cover the whole R1).
- µRWell with 2-D, 10 stereo, strip readout with capacitive sharing, is the chosen technology

CLAS12 Luminosity upgrade - Phase 1 - µRWELL FD

The device is composed of:

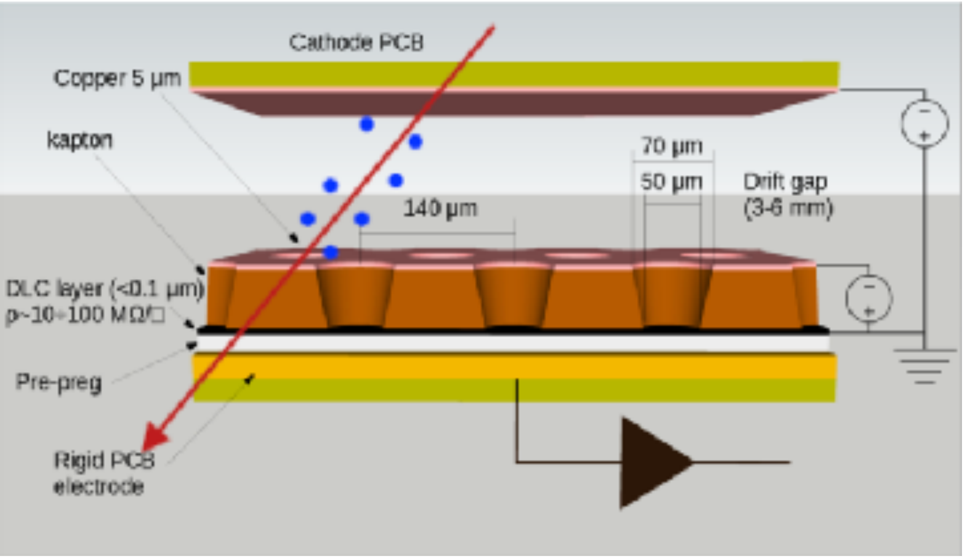
- Drift/Cathode PCB defining the gap
- Amplification stage + DLC film + Readout PCB
  - The “well” acts as a multiplication channel for the ionization produced in the gas of the drift gap

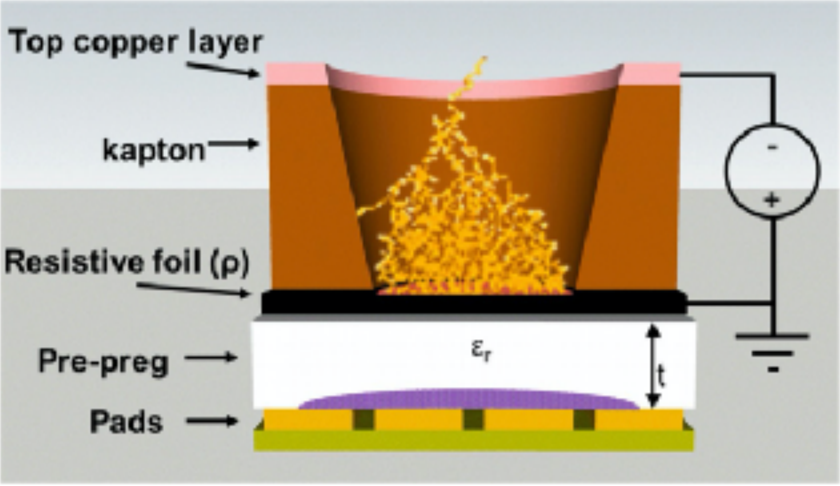
µRWELL features:

- Compactness
- Easy assembly
- Intrinsic spark quenching

µRWELL performances:

- Gain: 10^4
- Rate capability up to 10 MHz
- Spatial resolution: ~ 100 µm



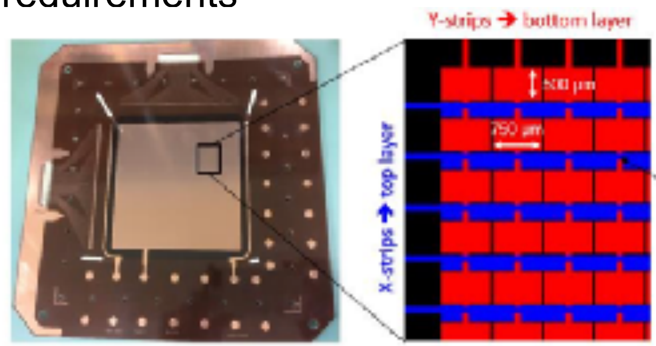


G. Bencivenni et al.; 2015_JINST_10_P02008

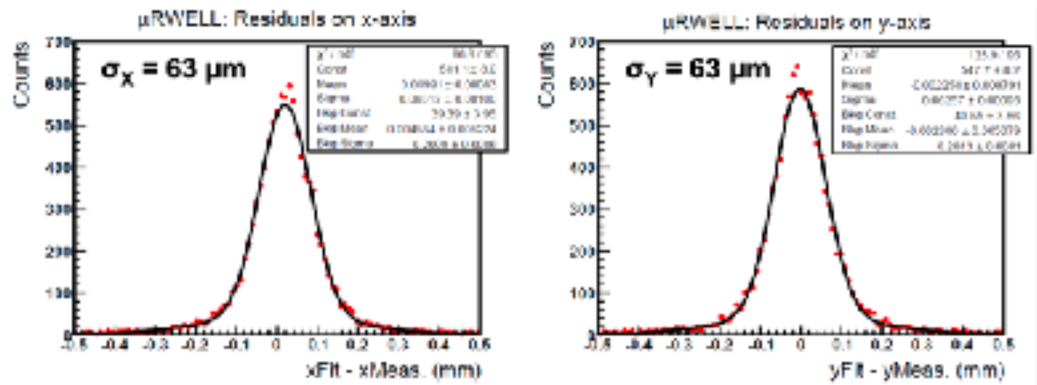
µRWELL R&D efforts

- A small prototype (10x10 cm2) of µRWELL detector with X-Y capacitive sharing strip (pitch ~ 800um) readout was built and tested at JLAB. Time and spatial resolution from beam tests data are well within requirements

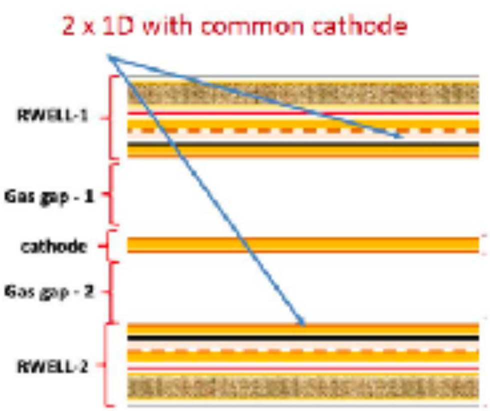
K. Gnanvo et al. NIM A 1047C (2023) 167782 https://doi.org/10.1016/j.nima.2022.167782

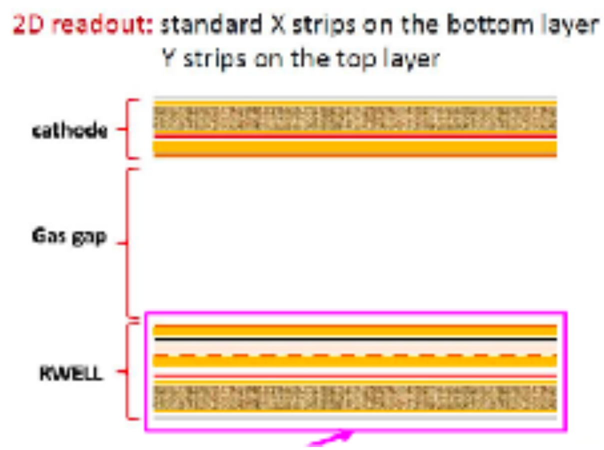


Credit to K. Gnanvo

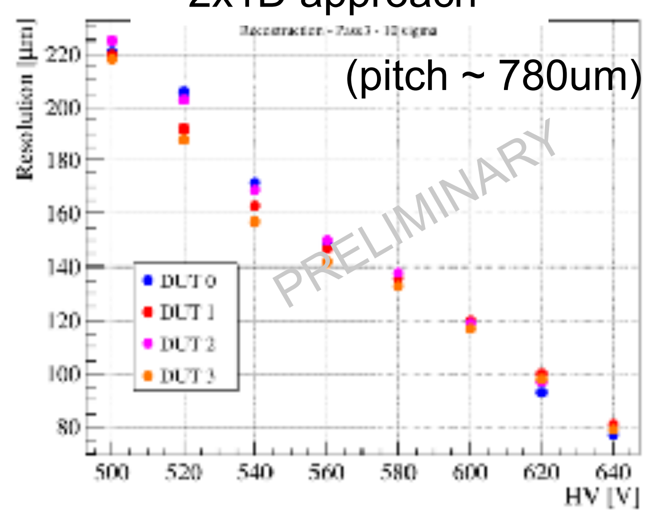


- R&D effort @ Italy devoted to develop alternative to 2D capacitive-sharing strip readout. Two approaches was tested at CERN:





2x1D approach

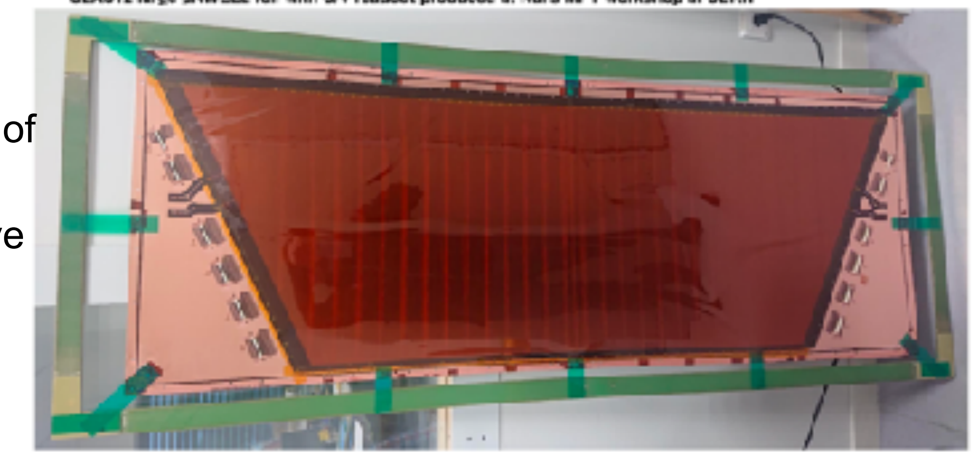


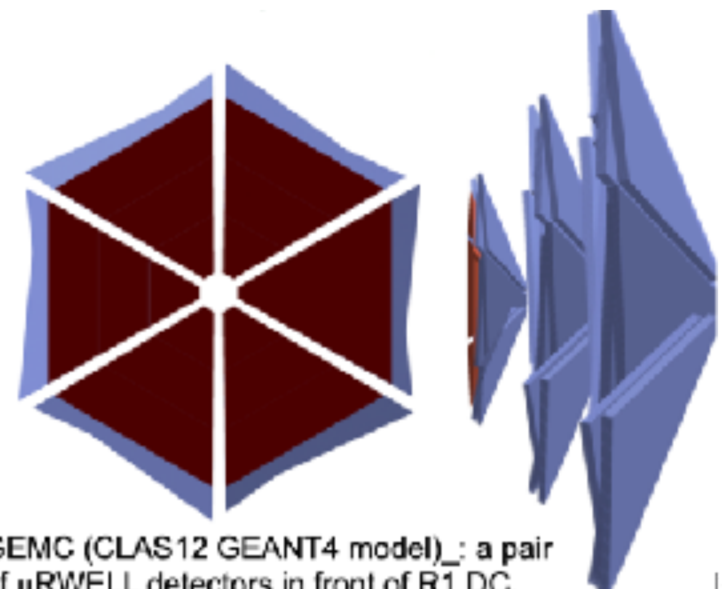
Credit to groups of A. D'Angelo and G. Bencivenni

CLAS12 Luminosity upgrade - Phase 1 - Status

- Simulations fully developed and show:
  - no sizable degradation of momentum resolution with pair of such detectors in front of R1 DC
  - existing tracking software can already achieve the desired efficiency at higher luminosities
- Full-scale, single-sector, prototype assembled at CERN, in collaboration with University of Virginia
  - Trapezoid with an active area of [1460 mm – 1012 mm] × 50 mm
  - U & V strips at 10-degree stereo pitch = 1 mm
  - Capacitive-sharing R/O scheme
- Timeline:
  - 2024: testing of prototype
  - 2025: fabrication of full 6 sectors
  - 2026: installation

CLAS12 large µRWELL foil with U/V readout produced at Rui's MPT workshop at CERN





GEMC (CLAS12 GEANT4 model)_: a pair of µRWELL detectors in front of R1 DC.

CLAS12 Luminosity upgrade - Phase 2 - Motivation

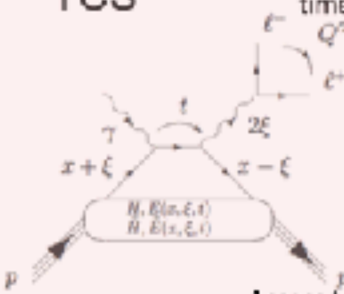
- CEBAF at the luminosity frontier, with large- acceptance detector systems, is a natural continuation of the JLab12 physics program and complementary to EIC

CLAS12 Flagship program – accessing GPDs through measurements of beam/target asymmetries and the cross sections of Compton processes (TCS and DVCS)

First experimental measurement with CLAS12 PRL 127, 262501 (2021)

TCS

Hard scale is defined by time-like photons



$$Re\ \mathcal{H}(\xi,t) = PV \int_{-1}^{1} dx\, C^{-}(\xi,x) H(x,\xi,t)$$

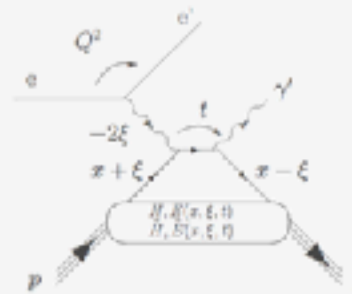
$$Im\ \mathcal{H}(\xi,t) = i\pi H(\xi,\xi,t)$$

Access to the Re-part of the Compton amplitude

Started in 2001, PRL 87, 182002.
Now is the flagship physics program

DVCS

Hard scale is defined by space-like photon

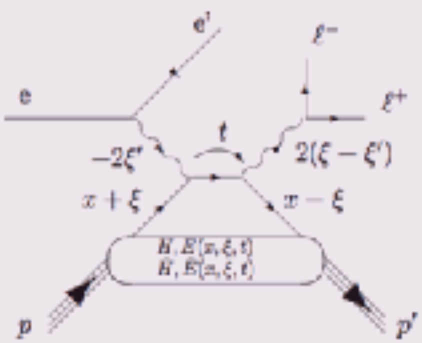


Jefferson Lab at the luminosity frontier is the only place in the world DDVCS can be measured!

µCLAS12 is one of two proposed facilities, another being SoLID in Hall-A, capable of carrying out such measurements.

DDVCS

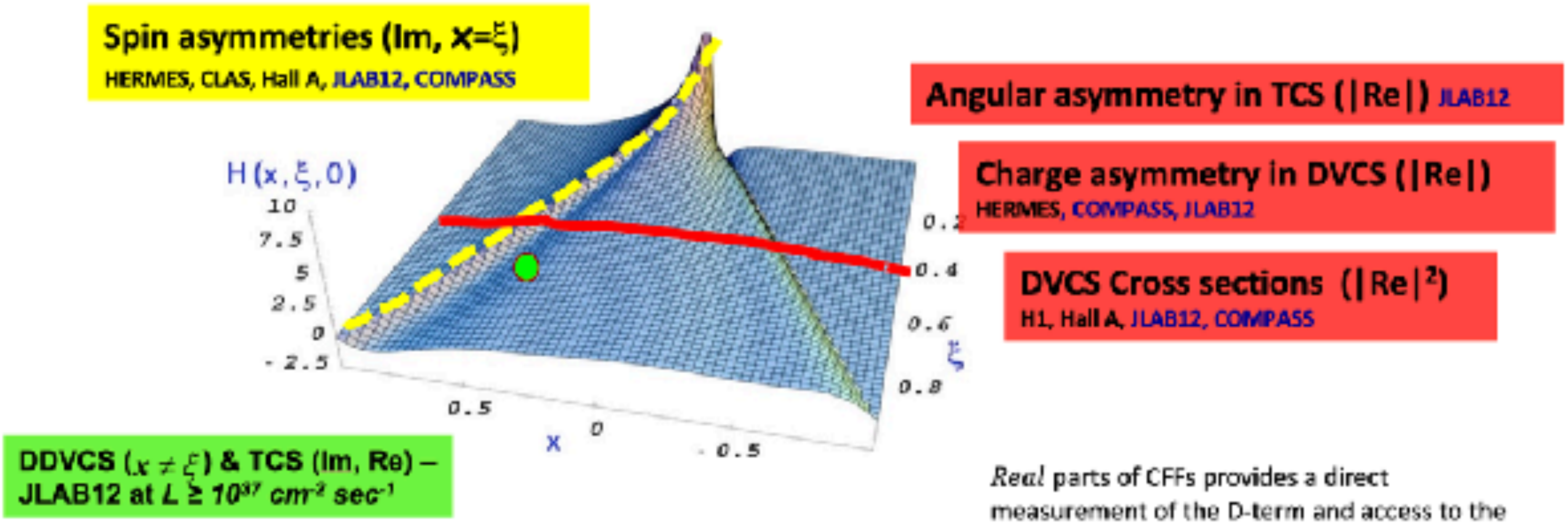
Both space-like and time-like photons can set the hard scale



$$\int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-(2\xi'-\xi)+i\epsilon} + \ldots$$

$$H(2\xi'-\xi,\xi,t) + H(-(2\xi'-\xi),\xi,t)$$

CLAS12 Luminosity upgrade - Phase 2 - Motivation



Real parts of CFFs provides a direct measurement of the D-term and access to the mechanical properties of the proton

But DDVCS cross section is three orders of magnitude smaller than DVCS

→ inaccessible to CLAS12 without large luminosity increase

CLAS12 Luminosity upgrade - Phase 2 - Plans

- **Two many challenges in DDVCS measurements**
  - Cross section is three orders of magnitude smaller than the DVCS cross section;
  - Ambiguities and anti-symmetrization issues with the decay leptons of the outgoing virtual photon and the incoming-scattered lepton.

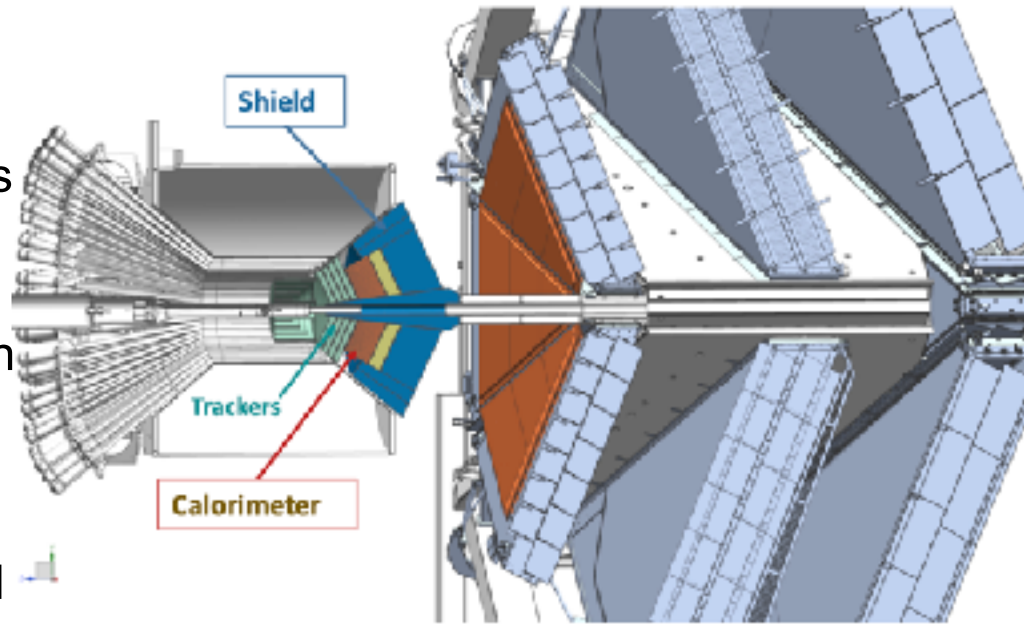
- **Both challenges can be solved by studying di-muon electro-production using upgrade CLAS12:**

$$ep \to e'p'\mu^+\mu^- \;\; @ \; few \times 10^{37} cm^{-2} sec^{-1}$$

CLAS12 Luminosity upgrade - Phase 2 - Plans

- Remove HTCC and block the CLAS12 forward with a W-shield and $PbWO_4$ calorimeter to prevent flooding of DC by EM background;
- Scattered electrons will be detected in the calorimeter, while shield will work as pion filter, as most of charged pions will shower and will not reach to the forward tracking system;
- Install fast, high rate MPGD trackers in front of the calorimeter for vertexing and inside the solenoid for recoil tagging.
- The existing downstream trackers and toroidal field become a muon spectrometer for luminaries of $10^{37} cm^{-1} s^{-1}$
- Time frame for Phase 2 is 6-8 years.

μCLAS12



Detector capable of measuring
$ep \rightarrow e'p'\mu^+\mu^-$ @ $L > 10^{37} cm^{-2} sec^{-1}$

μCLAS12-DDVCS Projections

- GRAPE event generator, BH only;
  - Kinematical coverage for DDVCS
    - Shown one t-bin, but measurements can be extended to $-t\sim 1$ GeV^2
    - The whole region is measured simultaneously

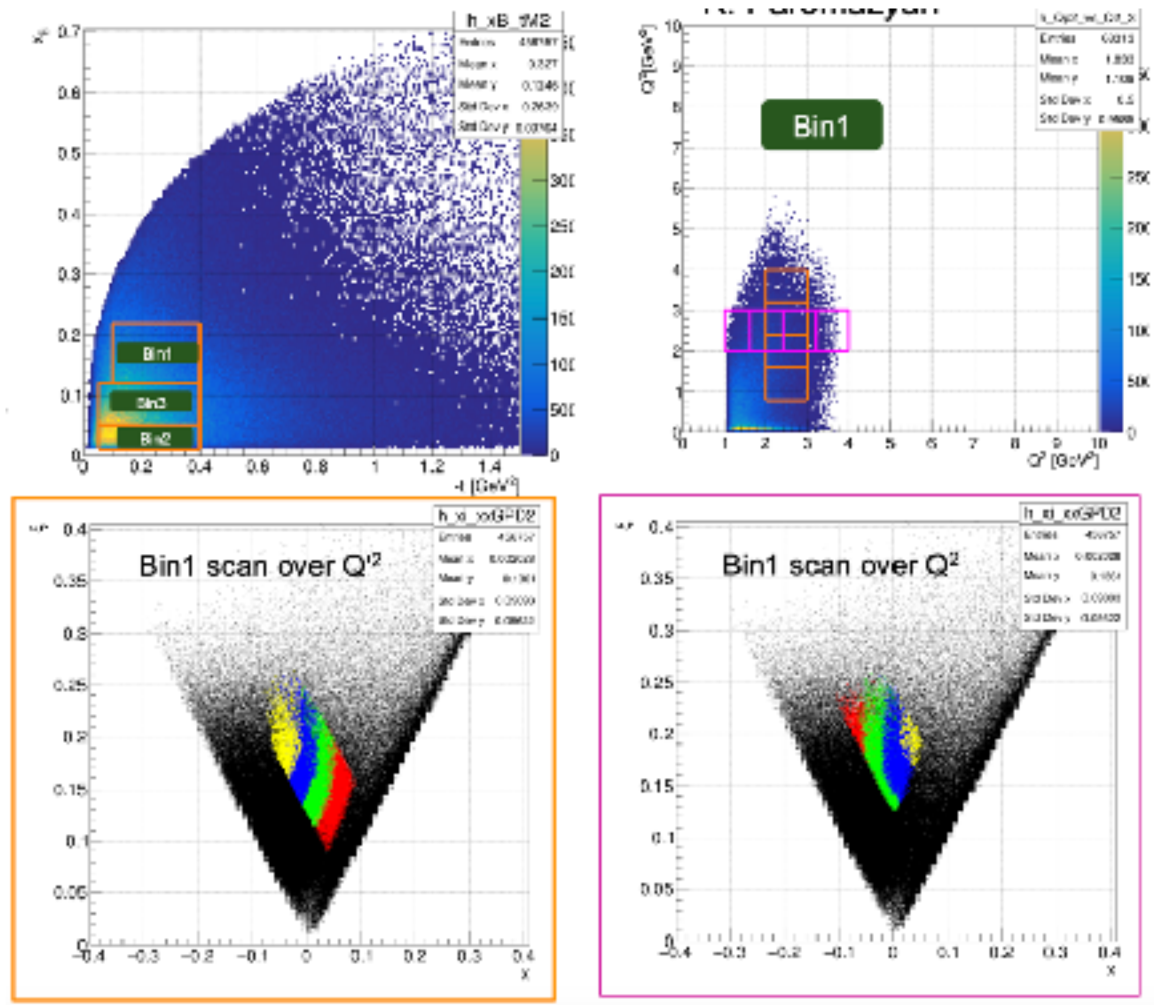
$$Q^2 = -q^2 = (e - e')^2$$

$$x_B = \frac{Q^2}{2pq}$$

$$Q'^2 \equiv M^2 = (l^+ - l^-)^2$$

$$\xi' = \frac{Q^2 + Q'^2}{2Q^2/x_B - Q^2 - Q'^2 + t}$$

$$\xi = \xi' \frac{Q^2 - Q'^2 + t/2}{Q^2 + Q'^2}$$



Credit to R. Paremuzyan

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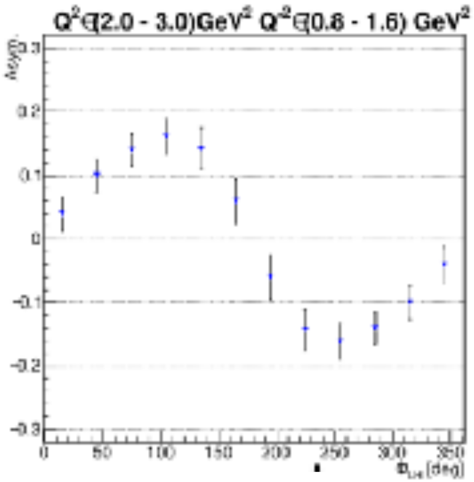
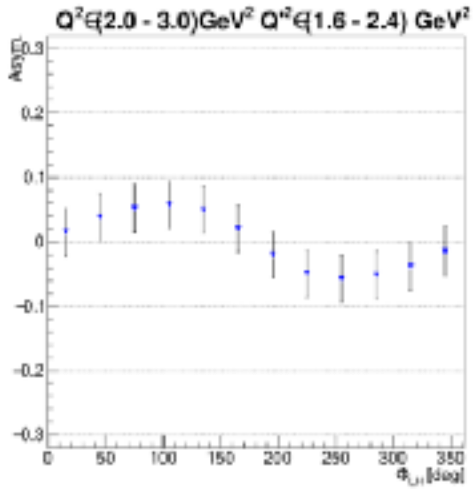
μCLAS12-DDVCS Projections

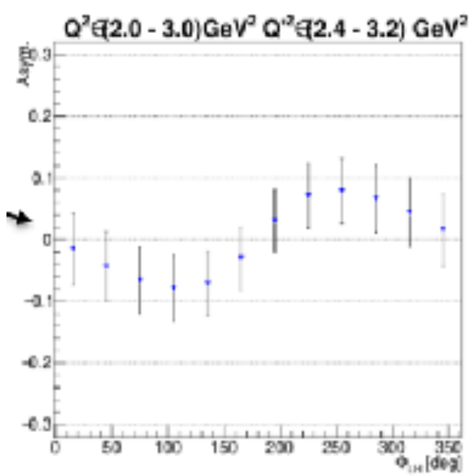
- Projections for Beam Spin Asymmetries for Bin1 for 100 days @ $10^{37}cm^{-1}s^{-1}$

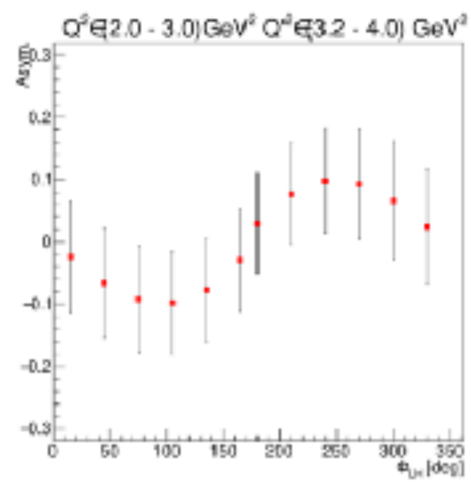




Space-like region, $Q^2 > Q'^2$

Time-like region, $Q^2 < Q'^2$





Credit to R. Paremuzyan

Summary

- CLAS12 has a diverse physics program, with its detector commissioned in 2018 and since then acquiring physics data.
- The detector performance is close to design after improvements from AI-assisted tracking, but luminosity upgrades will greatly help efficiently execute the existing physics program and facilitate new physics opportunities.
- The two-stage upgrade is planned for the CLAS12 luminosity upgrade.
  - Phase-I, in progress, will allow running x2 higher than the designed luminosity with an additional, fast tracking layer and en route in the next 3 years.
  - Phase-II upgrade, 5 to 8 years, will allow running CLAS12 at two orders higher luminosity
- µCLAS12 in the phase-II is one of only two facilities in the world that can measure DDVCS, extending access to GPDs into new kinematic space.